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(54) **FRACTURING PUMP ASSEMBLY AND METHOD THEREOF**

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(51) **Int. Cl.**

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F04B 23/06	(2006.01)
F15B 15/04	(2006.01)
E21B 43/26	(2006.01)
F04B 17/03	(2006.01)

(52) **U.S. Cl.**

CPC ***F04B 9/107*** (2013.01); ***E21B 43/26*** (2013.01); ***F04B 17/03*** (2013.01); ***F04B 23/06*** (2013.01); ***F15B 15/04*** (2013.01)

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CPC F04B 9/02; F04B 9/025; F04B 9/10; F04B 9/103; F04B 9/107; F04B 47/02; F04B 47/04; F04B 23/06; F04B 35/01; F04B 35/04; F04B 15/02; F04B 17/03; E21B 43/25; E21B 43/17; E21B 34/10; E21B 43/26; E21B 34/106; F15B 15/038; F15B 7/001; F15B 15/04; F15B 47/001

USPC 417/225, 226, 400; 92/136; 60/545, 567

See application file for complete search history.

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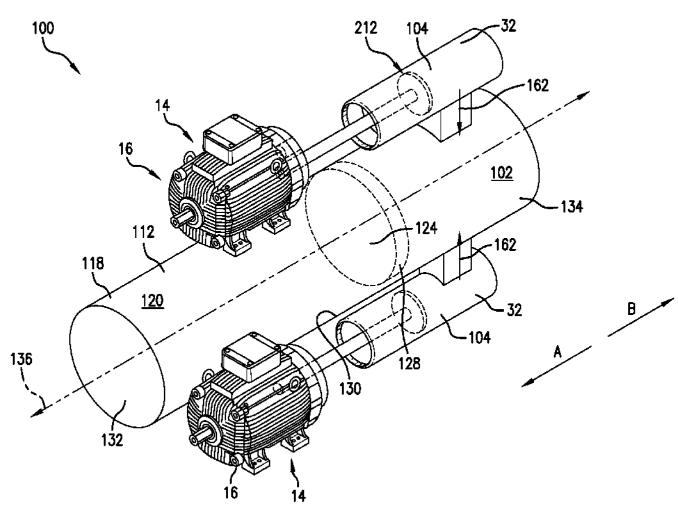
(57) **ABSTRACT**

A fracturing pump assembly includes an intensifier including a hydraulic cylinder, a compression member arranged within the hydraulic cylinder and a rotatable member, wherein the compression member is linearly actuated within the hydraulic cylinder by rotation of the rotatable member.

18 Claims, 6 Drawing Sheets



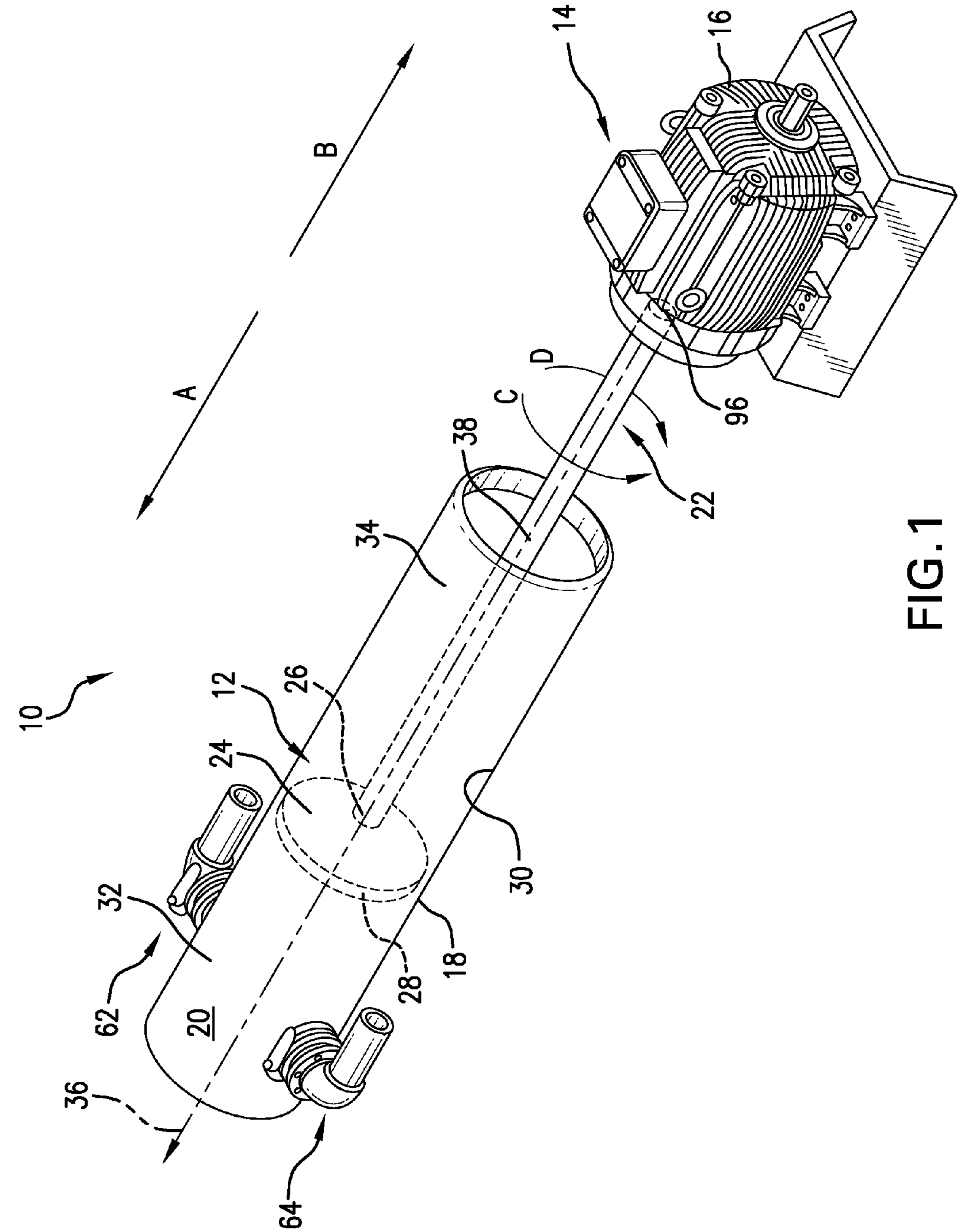


FIG. 1

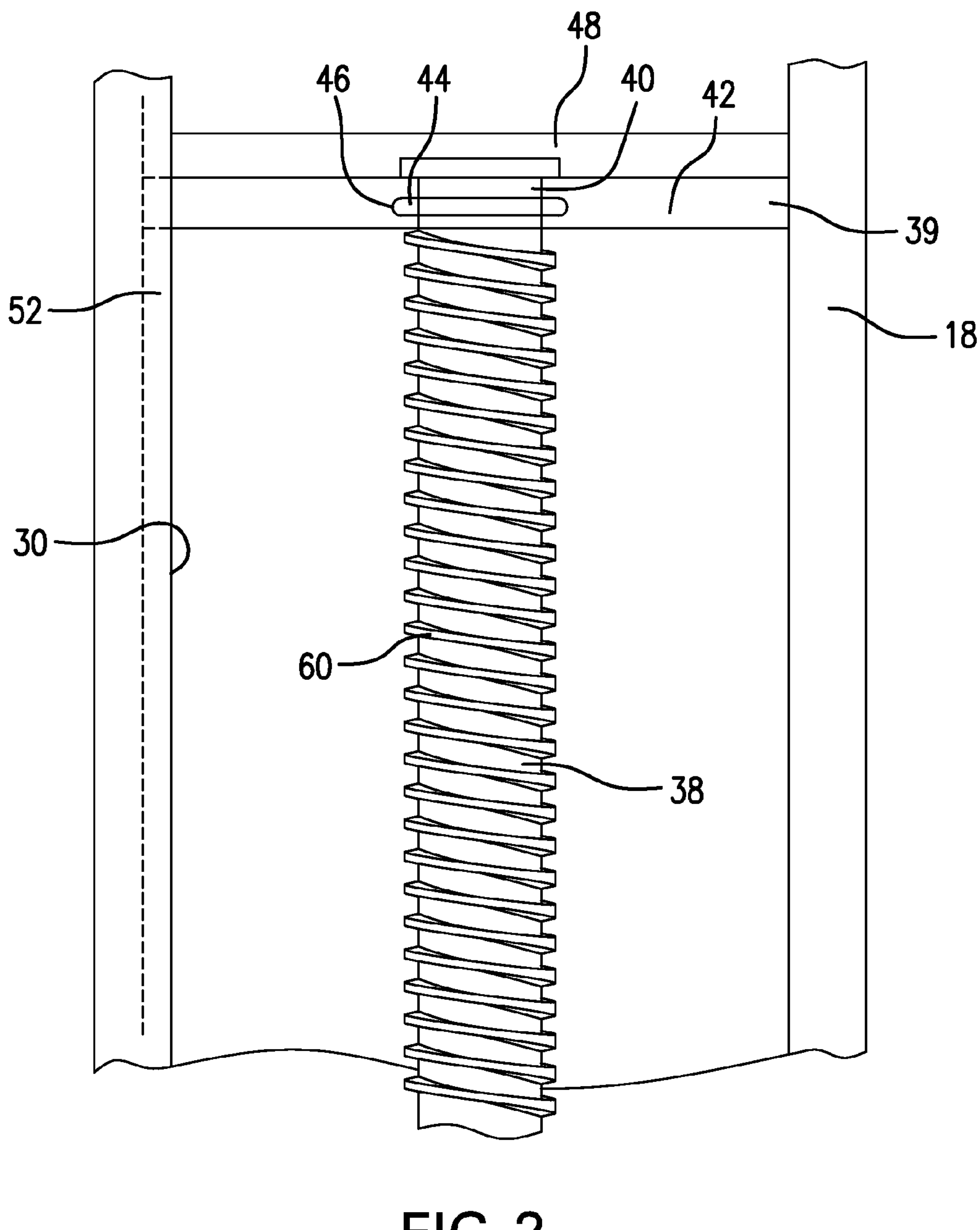


FIG.2

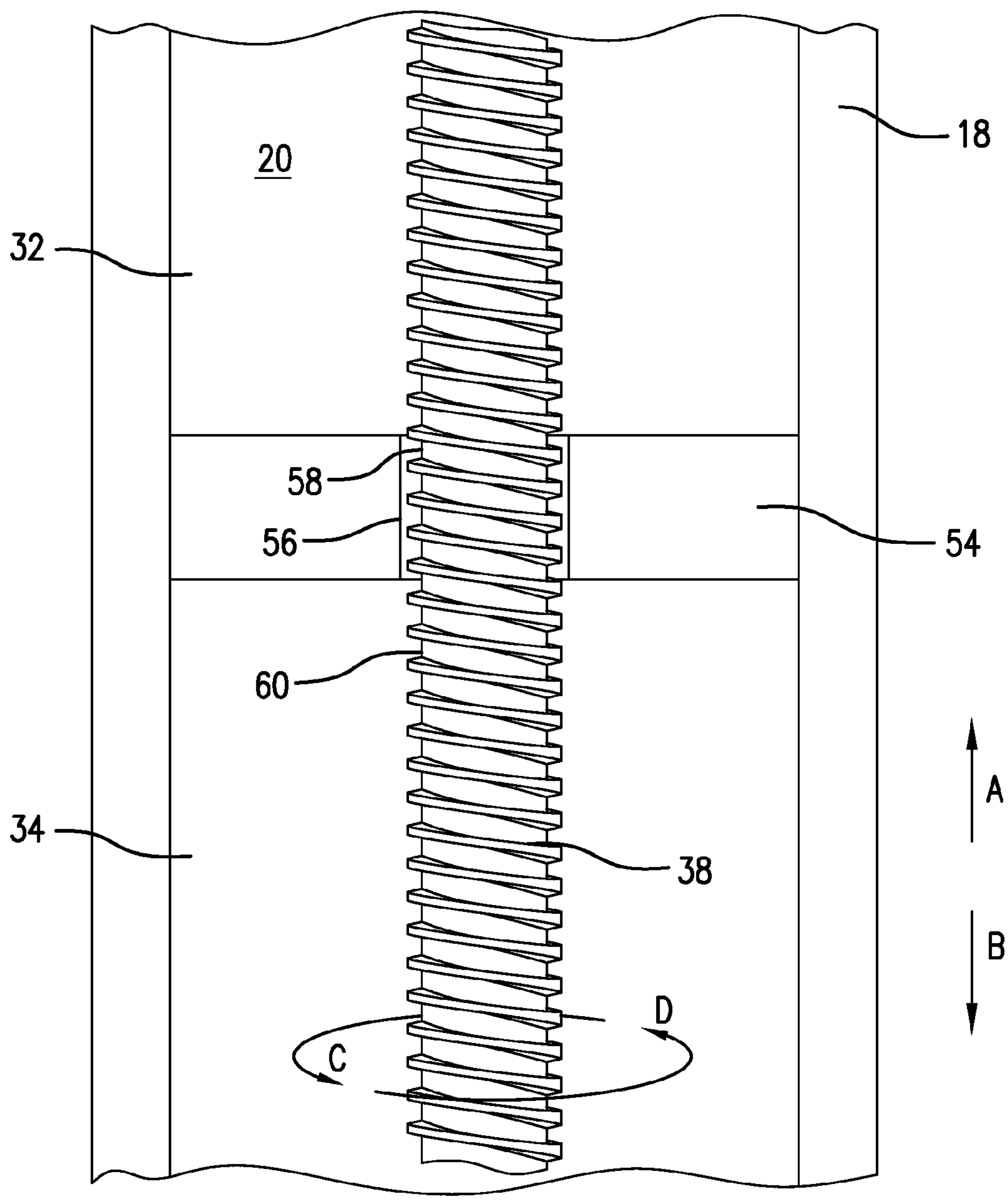


FIG.3

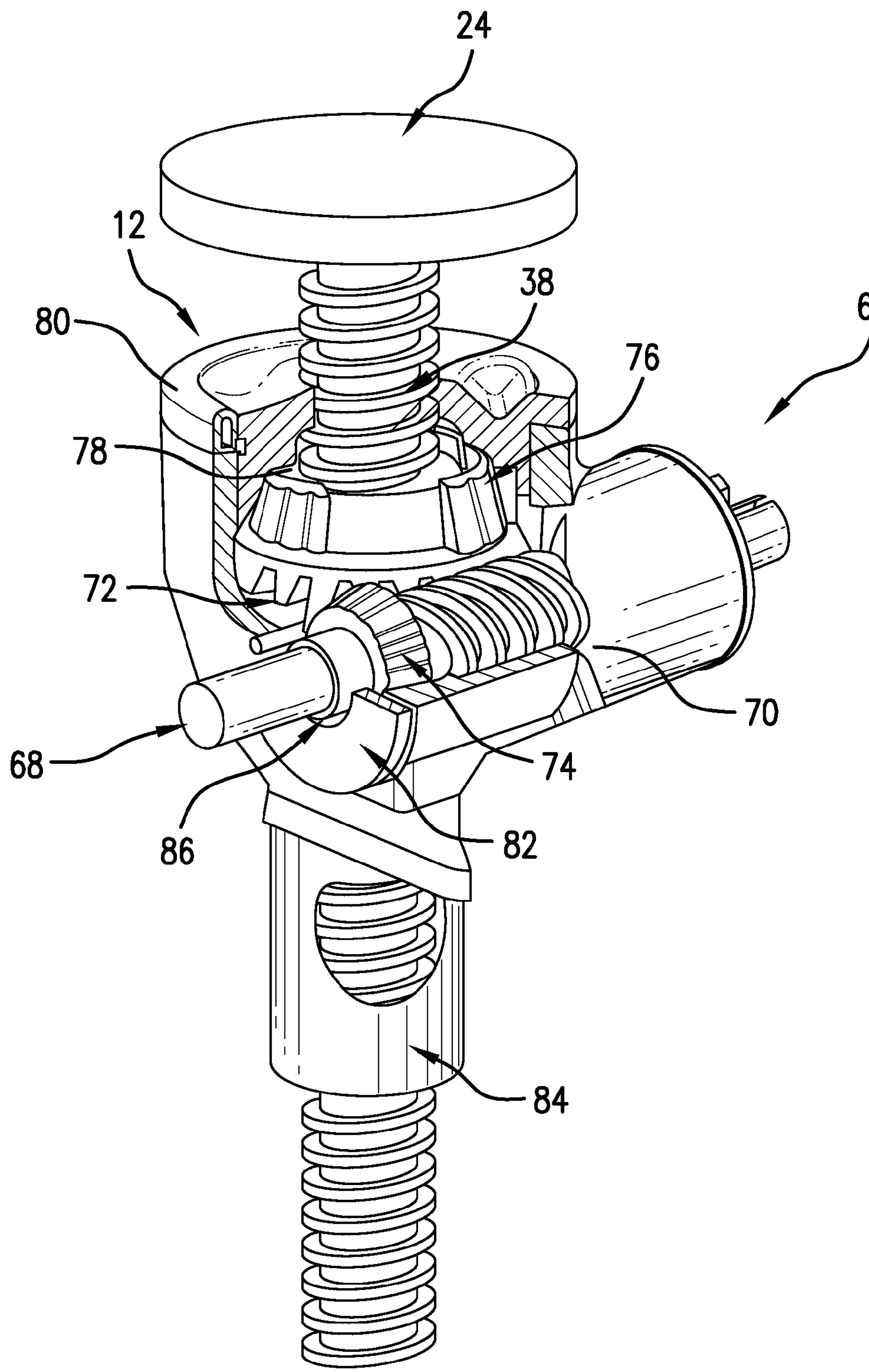


FIG.4

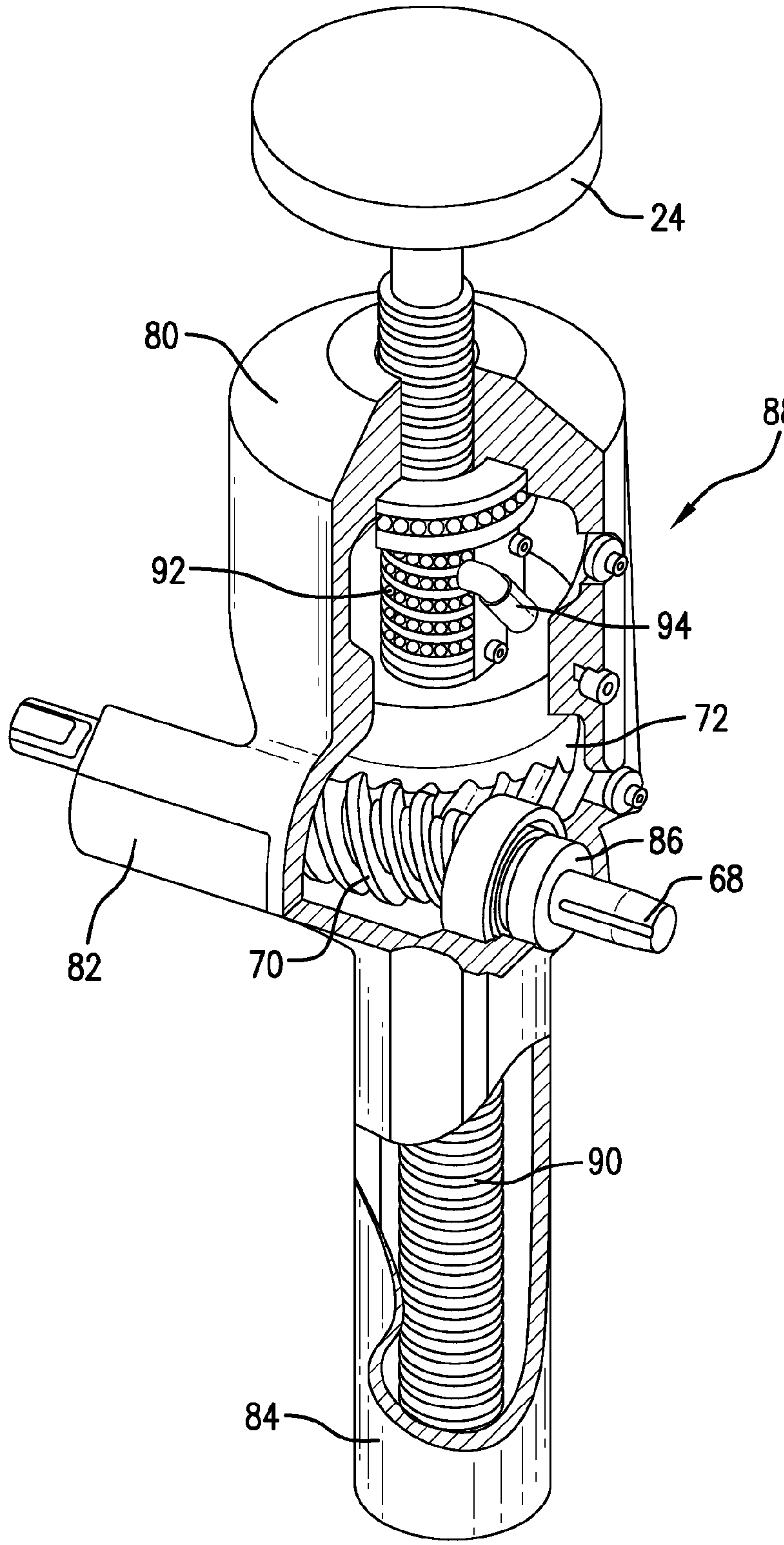


FIG.5

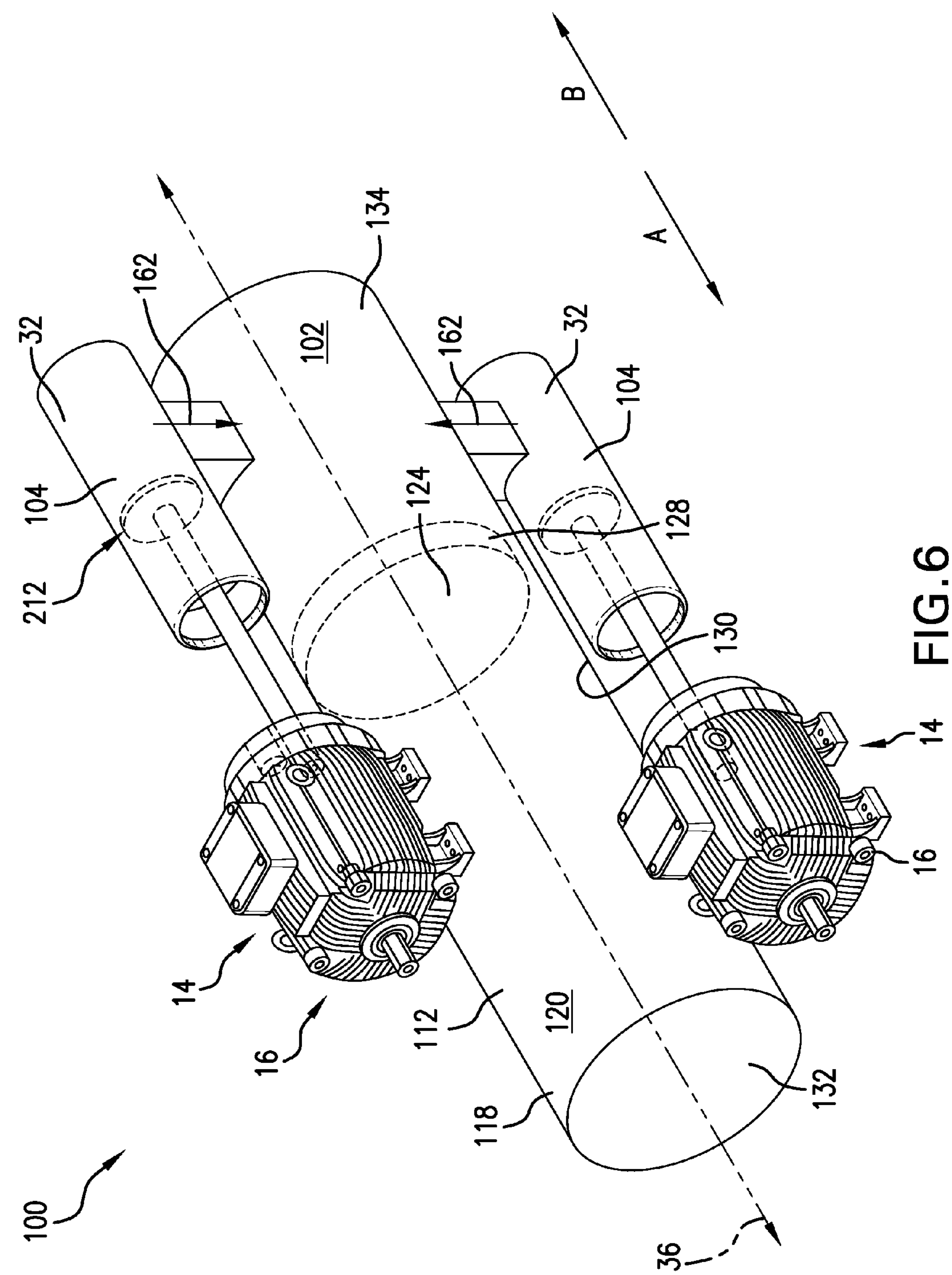

100
14
16
112
120
118
132
136
212
104
32
162
102
134
124
128
130
A
B

FIG.6

FRACTURING PUMP ASSEMBLY AND METHOD THEREOF

BACKGROUND

In the drilling and completion industry, the formation of boreholes for the purpose of production or injection of fluid is common The boreholes are used for exploration or extraction of natural resources such as hydrocarbons, oil, gas, water, and alternatively for CO2 sequestration. To increase the production from a borehole, the production zone can be fractured to allow the formation fluids to flow more freely from the formation to the borehole. The fracturing operation includes pumping fluids at high pressure towards the formation to form formation fractures. To retain the fractures in an open condition after fracturing pressure is removed, the fractures must be physically propped open, and therefore the fracturing fluids commonly include solid granular materials, such as sand, generally referred to as proppants. Other components of the fracturing fluids typically include water, gel, or other chemical additives.

To pump the fracturing fluids at the high pressures required for fracturing, a series of mechanical pumps having relatively short strokes and relatively high cycles per minute are employed. Such pumps tend to fatigue rather quickly because of the extreme pressures and the high cycles per minute rate of operation. Further aggravating the system is the fracturing fluid itself, which is either abrasive due to the proppant concentration or corrosive due to an acidic concentration or both The intensifiers include hydraulic cylinders that pump the hydraulic fluid down the borehole by being stroked from another cylinder.

To decrease the strain, pumping systems have been designed to have a longer stroke in order to reduce the number of fatigue and wear pressure cycles for longer service life. Pumping rams which receive working fluid through inlets and discharge working fluid through outlets are connected to power rams which receive fluid to affect the forward pumping strokes of the ram assemblies. Such an intensifier also includes a pre-charged accumulator for driving a pair of twin return rams to affect the return strokes of the ram assemblies.

While the long stroke intensifier is an improvement over pumping systems having shorter strokes, as time, manpower requirements, and mechanical maintenance issues are all variable factors that can significantly influence the cost effectiveness and productivity of a fracturing operation, the art would be receptive to improved apparatus and methods for reducing valve cycles and maintenance issues in a fracturing fluid pump.

BRIEF DESCRIPTION

Disclosed herein is a fracturing pump assembly which includes an intensifier including a hydraulic cylinder, a compression member arranged within the hydraulic cylinder and a rotatable member, wherein the compression member is linearly actuated within the hydraulic cylinder by rotation of the rotatable member.

Also disclosed is a method of pressurizing fracturing fluid for delivery to a borehole including rotating a screw rod in a first rotational direction within a hydraulic cylinder, linearly moving a compression member operatively engaged with the screw rod within the hydraulic cylinder. The compression member separates a compression area of the hydraulic cylinder filled with a first fluid from an area of the hydraulic cylinder void of the first fluid and pressurizes the first fluid within the compression area via linear actuation of the compression member in a first axial direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. **1** shows a perspective view of an exemplary embodiment of a fracturing pump assembly including an exemplary intensifier;

FIG. **2** shows a cross-sectional view of an exemplary intensifier for the fracturing pump assembly of FIG. **1**;

FIG. **3** shows a cross-sectional view of another exemplary intensifier for the fracturing pump assembly of FIG. **1**;

FIG. **4** shows a perspective cut-away view of an exemplary jack screw drive for driving the intensifier of FIG. **1**;

FIG. **5** shows a perspective cut-away view of an exemplary ball screw drive for driving the intensifier of FIG. **1**; and,

FIG. **6** shows a perspective view of another exemplary embodiment of a fracturing pump assembly including exemplary primary and secondary intensifiers.

DETAILED DESCRIPTION

A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

With reference to FIG. **1**, an exemplary embodiment of a fracturing fluid pump assembly **10**, alternately termed a fracturing pump assembly or more simply a frac pump, employs an intensifier **12** actuated by a power source **14**. In the illustrated embodiment, the power source **14** is an electric motor **16**, although other power sources, motors, engines, and prime movers could alternatively be employed to actuate the intensifier **12**. Depending on the location of the electric motor **16** with respect to the intensifier **12**, the pump assembly **10** further includes any gearing necessary to enable actuation of the intensifier **12** by the electric motor **16**. The intensifier **12** includes a long hydraulic cylinder **18** to pump a fluid **20**, such as a fracturing fluid including but not limited to a proppant filled slurry, down the borehole while being pressurized by the intensifier **12**. While a conventional fracturing pump assembly utilizes a second cylinder to reciprocatingly stroke within the cylinder **18** in an axial direction of the cylinder **18** via hydraulic pressure, an exemplary embodiment of the pump assembly **10** incorporates a screw mechanism **22**, such as a jack screw mechanism or ball screw mechanism, that is turned by the electric motor **16**. The use of the screw mechanism **22** reduces valve cycles, thus providing an intensifier **12** requiring reduced valve maintenance.

In an exemplary embodiment, a compression member **24**, such as a plate or piston, that at least substantially fills an interior diametrical cross-section of the cylinder **18** is operatively connected to the screw mechanism **22**, such as at a first end portion **26** of a rotatable member or screw rod **38**. An external periphery **28** of the compression member **24** engages closely with an interior periphery **30** of the cylinder **18** for adequately compressing the fluid **20** within a compression area **32** of the cylinder **18**. The compression member **24** entirely or at least substantially separates the compression area **32** of the cylinder **18** from a rod side area **34** of the cylinder **18**. As will be understood by a review of FIG. **1**, the size of the compression area **32** of the cylinder **18** will decrease when the compression member **24** moves along longitudinal axis **36** in direction A within the cylinder **18** and the size of the rod side area **34** of the cylinder **18** will increase when the compression member **24** moves in direction A. Likewise, the size of the compression area **32** of the cylinder **18** will increase when the compression member **24** moves in direction B, opposite direction A, within the cylinder **18** and the size of the rod side area **34** of the cylinder **18** will decrease when the compression member **24** moves in direction B.

The compression member **24** of the screw mechanism **22** moves in linear directions A, B along the longitudinal axis **36** of the cylinder **18** via screw rod **38** of the screw mechanism **22**. The screw rod **38** rotates within the cylinder **18** and the screw mechanism **22** converts the rotational motion of the screw rod **38** to a linear motion of the compression member **24**. The screw rod **38** includes a helical thread **60** (FIG. **2**) such that rotation of the screw rod **38** in rotational direction C linearly moves the compression member **24** in one of directions A, B, while rotation of the screw rod **38** in opposite rotational direction D linearly moves the compression member **24** in the other of directions A, B. In an exemplary embodiment, rotation of the screw rod **38** of the screw mechanism **22** is accomplished via a mechanical engagement with the electric motor **16**. Such mechanical engagement can be direct as shown in FIG. **1**, where the screw rod **38** and a rotating output shaft **96** of the electric motor **16** are mechanically configured to interact directly or via gears. Alternatively, in another exemplary embodiment (not shown) power from the electric motor **16** can be delivered to the pump assembly **10** from a remote location and the screw rod **38** is rotated via a gear box which is actuated by the remotely located electric motor **16** or other power source **14**.

In one exemplary embodiment, the compression member **24** can be fixedly attached to the first end portion **26** of the screw rod **38** and rotate within the cylinder **18** with rotation of the screw rod **38**. In such an embodiment, the screw rod **38** would also be configured to move linearly within the cylinder **18** upon rotation of the screw rod **38**. In another exemplary embodiment, as depicted in FIG. **2**, a compression member **39** can include an inner portion **40** rotatably connected to and positioned concentrically within an outer portion **42**. An external mating surface **44** of the inner portion **40** cooperates with an internal mating surface **46** of the outer portion **42** to allow for the rotation of the inner portion **40** within the outer portion **42**. Ball bearings (not shown) may be disposed between the mating surfaces **44**, **46** to reduce friction there between. A fluid engaging plate **48** is disposed on the outer portion **42** and covering the compression member **39** to prevent the fluid **20** contained in the compression area **32** from contacting the working elements of the screw mechanism **22**. To prevent the outer portion **42** from rotating with the inner portion **40** and within the cylinder **18**, outer mating features **50** of the outer portion **42** can additionally be provided to engage with one or more linear slots **52** or protrusions (not shown) along the interior periphery **30** of the cylinder **18**. In such an arrangement, as the screw rod **38** rotates with the inner portion **40**, the outer portion **42** only moves linearly within the cylinder **18**, and the screw rod **38** rotates with respect to the outer portion **42**.

In another exemplary embodiment, as shown in FIG. **3**, a compression member **54** is arranged as a "traveling nut" on the screw rod **38**. The compression member **54** includes a screw receiving aperture **56** having threads **58** to cooperate with threads **60** on the screw rod **38**. As in the previous embodiments, the compression member **54** separates a compression area **32** filled with fluid **20** from area **34** of the cylinder **18**. In this exemplary embodiment, however, the screw rod **38** occupies at least a portion of the compression area **32**. The screw rod **38** is configured to rotate in directions C and D, however only compression member **54** is configured to translate axially in directions A and B. In such an embodiment, since the screw rod **38** rotates but does not move linearly, the screw rod **38** can be connected directly and axially with a rotating output shaft **96** of electric motor **16**, as shown in FIG. **1**.

FIG. **4** shows an exemplary embodiment of a jack screw mechanism **66** for driving the intensifier **12** of FIG. **1**. For clarity, the hydraulic cylinder **18** is not shown. The jack screw mechanism **66** is at least substantially self-locking in that when the compression member **24** is moved in a first axial direction by a rotational force on the screw rod **38** and that rotational force on the screw rod **38** is removed, the screw rod **38** will not rotate in an opposite direction. However, intentional rotational force on the screw rod **38** in an opposite direction allows for movement of the compression member **24** in a second axial direction opposite the first axial direction. The jackscrew mechanism **66** is suitable for large amounts of force, pressure, and weight, and can accommodate varying sizes of intensifiers **12** for the pump assembly **10**. The jack screw mechanism **66** is driven by the electric motor **16** shown in FIG. **1** via the input shaft **68** of a worm **70**. The worm **70** interacts with a worm gear **72** which in turn rotates the screw rod **38** for moving the compression member **24** in directions A or B as previously described. The worm gear **72** includes a threaded aperture **78** configured to engage and rotate the screw rod **38** to linearly translate the screw rod **38** and compression member **24**. Input shaft bearings **74** as well as upper thrust bearing **76** and lower thrust bearing (not shown) may be additionally provided for supporting the input shaft **68** and worm gear **72**. Protective housings **80**, **82**, **84** and seals **86** are additionally provided as necessary to protect working components.

While FIG. **4** depicts the worm gear **72** including threaded aperture **78** configured to engage and rotate the screw rod **38** to linearly translate the screw rod **38** and compression member **24**, in an alternative exemplary embodiment, the worm gear **72** is fixedly attached to the screw rod **38** such that rotation of the worm gear **72** rotates the screw rod **38** but does not linearly translate the screw rod **38** within the worm gear **72**. Instead, the compression member **24** is arranged as compression member **54** shown in FIG. **3**, such that the compression member **54** is linearly translated with respect to screw rod **38**.

In another exemplary embodiment of the intensifier **12**, FIG. **5** shows an exemplary ball screw mechanism **88** for driving the intensifier **12** of FIG. **1**. To minimize the amount of friction experienced between the sliding contact areas of the worm gear **72** and the screw rod **38** within the jack screw mechanism **66** shown in FIG. **4**, the intensifier **12** alternatively includes the ball screw mechanism **66**. The ball screw mechanism **88** includes a screw rod **90** different from the screw rod **38** in that the thread profile of the screw rod **90** is semicircular to properly engage with ball bearings **92** of the ball screw mechanism **88**. The ball screw mechanism **88** also includes an input shaft **68** engageable with or otherwise rotated by a power source **14**, a worm **70**, worm gear **72**, and a compression member **24**. The ball screw mechanism **88** further includes housings **80**, **82**, **84** and seals **86** as appropriate for a particular application. The ball screw mechanism **88** further includes a ball return **94** configured to direct ball bearings **92** from one end of the ball screw mechanism **88** to the other. The ball screw mechanism **88** is an efficient converter of rotary to linear motion, and is more mechanically efficient than the jack screw mechanism **66** due to reduced friction. The rolling contact of the ball screw mechanism **88** also eliminates or at least substantially reduces stutter when the pump assembly **10** is started or direction is changed, however the ball screw mechanism **88** is also slightly more complicated than the jack screw mechanism **66** and therefore may not be a suitable choice for all applications.

With further reference to FIG. **1**, a quantity of fluid **20** to be delivered to the borehole is provided to the compression area **32** of the cylinder **18** by a suction valve **62**. When the compression member **24** moves in direction B, the suction valve is opened allowing for entry of the fluid **20** into the compression area **32**. When the compression member **24** moves in direction A, a discharge valve **64** is opened allowing for exit of the fluid **20** from the compression area **32**. The pressure of the fluid **20** exiting the discharge valve **64** will be greater than the pressure of the fluid **20** entering the compression area **32** via the suction valve **62**. The suction and discharge valves **62**, **64** can be rated to open and close when certain pressure limits are met.

FIG. **6** shows an alternative exemplary embodiment of a fracturing fluid pump assembly **100** including a primary intensifier **112**. In this exemplary embodiment, the primary intensifier **112** includes a long hydraulic cylinder **118** to pump a fluid **120**, such as but not limited to fracturing fluid and slurry, down the borehole while being pressurized by the intensifier **112**. The fluid **120** is pressurized by a hydraulically movable compression member **124** configured to move linearly within the cylinder **118** in directions A or B along longitudinal axis **136** of the hydraulic cylinder **118**. The compression member **124** moves via the pressurized force of a fluid **102**, such as but not limited to oil. The compression member **124** at least substantially separates a first area **132** of the hydraulic cylinder **118** receiving the fluid **120** from a second area **134** of the hydraulic cylinder **118** receiving the fluid **102**. The compression member **124**, such as a plate, at least substantially fills an interior diametrical cross-section of the cylinder **118**. That is, an external periphery **128** of the compression member **124** engages closely with an interior periphery **130** of the cylinder **118** for adequately compressing the fluid **120** within the first area **132** of the cylinder **118**. As will be understood by a review of FIG. **6**, the size of the first area **132** of the cylinder **118** will decrease when the compression member **124** moves in direction A within the cylinder **118** and the size of the second area **134** of the cylinder **118** will increase when the compression member **124** moves in direction A. Likewise, the size of the first area **132** of the cylinder **118** will increase when the compression member **124** moves in direction B within the cylinder **118** and the size of the second area **134** of the cylinder **118** will decrease when the compression member **124** moves in direction B.

To increase or decrease the volume of the fluid **102** within the second area **134** of the hydraulic cylinder **118** to affect movement of the compression member **124**, the second area **134** is connected to a compression area **32** of one or more secondary intensifiers **212**. The secondary intensifiers **212** of FIG. **6** are actuated in a substantially same manner as the intensifier **12** shown in FIG. **1**. The secondary intensifiers **212** of the frac pump assembly **100** of FIG. **6**, however, do not include the suction and discharge valves **62**, **64** shown in FIG. **1**. Instead, the pump assembly **100** includes an operable valve **162** between the secondary intensifier **212** and the primary intensifier **112**. That is, the valve **162** discharges fluid **104** contained within the compression area **32** to the second area **134** of the hydraulic cylinder **118**, and the fluid **104** is the same as the fluid **102**, such as oil, instead of a slurry **20** as in the pump assembly **10** of FIG. **1**. Although not shown, suction and discharge valves **62**, **64** can be provided on the primary intensifier **112** to deliver fluid **120** to and from the first area **132** of the primary intensifier **112**. In an exemplary embodiment of the pump assembly **100**, the secondary intensifiers **212** are smaller than the primary intensifier **112** such that multiple power sources **14**, such as multiple electric motors **16**, can be provided. With one power source **14** per secondary intensifier **212**, the overall size of each power source **14**, secondary intensifier **212**, and drive mechanism used in the pump assembly **100** of FIG. **6** can be decreased as compared to the power source **14**, intensifier **12**, and drive mechanism **66**, **88** for a comparable amount of fluid **20**, **120** (slurry) pumped to the borehole. The secondary intensifiers **212** can be constructed in a manner similar to any of the exemplary embodiments described above with respect to FIGS. **1-5**.

While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another. Furthermore, the use of the terms a, an, etc. do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item.

What is claimed:

1. A fracturing pump assembly comprising:

a primary intensifier including:
- a primary hydraulic cylinder;
- a primary compression member linearly actuable within the primary hydraulic cylinder in opposing first and second directions by a first fluid; and,

a plurality of secondary intensifiers in fluid communication with the primary intensifier, each secondary intensifier including:
- a secondary hydraulic cylinder;
- a secondary compression member arranged within the secondary hydraulic cylinder; and,
- a rotatable member, wherein the secondary compression member is linearly actuated within the secondary hydraulic cylinder by rotation of the rotatable member;

wherein the first fluid is discharged into the primary hydraulic cylinder by each of the plurality of secondary intensifiers to move the primary compression member in the first direction.

2. The fracturing pump assembly of claim **1**, wherein, in each secondary intensifier amongst the plurality of secondary intensifiers, the rotatable member is a screw rod.

3. The fracturing pump assembly of claim **2**, further comprising, in each secondary intensifier amongst the plurality of secondary intensifiers,

a worm gear configured to rotate the screw rod, and a worm configured to rotate the worm gear.

4. The fracturing pump assembly of claim **1**, wherein the primary hydraulic cylinder is larger than each of the secondary hydraulic cylinders.

5. The fracturing pump assembly of claim 1, wherein the primary compression member separates the first fluid from a second fluid within the primary hydraulic cylinder, and the second fluid is a fracturing fluid.

6. The fracturing pump assembly of claim 1 wherein the secondary compression member is rotatable with the rotatable member.

7. The fracturing pump assembly of claim 1, wherein in each secondary intensifier amongst the plurality of secondary intensifiers, the rotatable member rotates with respect to the secondary compression member.

8. The fracturing pump assembly of claim 1, wherein, in each secondary intensifier amongst the plurality of secondary intensifiers, linear movement of the rotatable member is restrained and the secondary compression member is linearly actuated with respect to the rotatable member.

9. The fracturing pump assembly of claim 1, further comprising, in each secondary intensifier amongst the plurality of secondary intensifiers, a power source rotating the rotatable member.

10. The fracturing pump assembly of claim 1, further comprising a valve between each of the secondary hydraulic cylinders and the primary hydraulic cylinder.

11. The fracturing pump assembly of claim 1, further comprising, in each secondary intensifier amongst the plurality of secondary intensifiers, a ball screw mechanism, the rotatable member including semi-circular threads receiving ball bearings of the ball screw mechanism.

12. The fracturing pump assembly of claim 1, wherein, in each secondary intensifier amongst the plurality of secondary intensifiers, the secondary compression member is movable in the opposing first and second directions.

13. The fracturing pump assembly of claim 12, wherein, in each secondary intensifier amongst the plurality of secondary intensifiers, movement of the secondary compression member in the second direction corresponds to movement of the primary compression member in the first direction.

14. A method of pressurizing fracturing fluid for delivery to a borehole, the method comprising:

providing the fracturing fluid within a first area of a primary hydraulic cylinder, a primary compression member separating the fracturing fluid from a first fluid within a second area of the primary hydraulic cylinder;

rotating a screw rod in a first rotational direction within a secondary hydraulic cylinder;

linearly moving a secondary compression member operatively engaged with the screw rod within the secondary hydraulic cylinder, the secondary compression member separating a compression area of the secondary hydraulic cylinder filled with the first fluid from an area of the secondary hydraulic cylinder void of the first fluid;

pressurizing the first fluid within the compression area via linear actuation of the secondary compression member in a first axial direction; and,

delivering pressurized first fluid from the compression area of the secondary hydraulic cylinder to the second area of the primary hydraulic cylinder to move the primary compression member in a second axial direction opposite the first axial direction.

15. The method of claim 14 wherein rotating the screw rod includes rotating the screw rod with an electric motor.

16. The method of claim 14, further comprising pressurizing the fracturing fluid with the primary compression member, the fracturing fluid different from the first fluid.

17. The method of claim 14 wherein rotating the screw rod includes rotating a worm configured to rotate a worm gear operatively engaged with the screw rod.

18. The method of claim 14 further comprising rotating the screw rod in a second rotational direction opposite the first rotational direction, rotation of the screw rod in the second rotational direction moving the secondary compression member in the second axial direction.

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